Fermi National Accelerator Laboratory

FERMILAB-Pub-92/85-A
March 1992

MASS LOSS AND THE POP II LITHIUM DIP *

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Abstract

It is shown that the recent observation of a dip in lithium abundances for high surface temperature (T $\sim$ 6300K) Pop II stars relative to the Pop II lithium plateau can be explained by main sequence mass loss. This explanation is identical to our previously proposed explanation for the Pop I lithium dip. It is assumed that the main sequence mass loss in both cases is associated with the instability strip intersecting the main sequence. This mass loss process can also decrease globlular cluster ages by $\sim$ 1 Gyr.

* Submitted to *The Astrophysical Journal Letters*

INTRODUCTION

Lithium abundances in Population II stars are well known to have potential cosmological significance (c.f. Yang et al. 1984 or Kawano, Schramm, & Steigman 1988). The observation of the Li abundance plateau in Pop II stars (Spite & Spite 1982; Hobbs & Duncan 1987; Rebolo, Molaro & Beckman 1988) is one of the major supporting observations regarding the validity of homogeneous Big Bang Nucleosynthesis (Walker et al. 1991 and ref. therein). The recent observation by Hobbs, Welty & Thorburn (1991) of certain high temperature Pop II stars with lithium abundances below the plateau could be naively construed as a potential problem of this cosmological picture. However, we argue here that the explanation for this Pop II lithium abundance dip below the plateau is probably due to the same process which causes the lithium abundance dip observed in the Pop I stars (Boesgaard & Trippico 1986, Hobbs & Pilachowski 1988) and therefore is not of cosmological significance. Nonetheless, the origin of these dips is of importance to stellar evolution. In particular, we will show that our previously proposed (Schramm, Steigman, & Dearborn 1990, hereafter referred to as SSD) main-sequence mass loss model for the Pop I lithium dip naturally explains the newly observed Pop II lithium dip. While the alternative diffusion explanation for the Pop I lithium dip (Michaud 1986) might also be extended to Pop II, it remains to be shown that such an extension could occur naturally. In any case, one should note that the surface temperature of the stars showing both the Pop I and Pop II dips is similar, but Pop II stars with low Fe/H have lower masses corresponding to the same surface temperature. Thus, the dip is clearly a surface effect and not a mass effect.

The essence of the SSD mass-loss hypothesis is to note that the temperature of the instability strip crosses the main sequence both for Pop I and Pop II near the observed lithium dip stars. Following Willson, Bowen, & Struck-Marcell (1987), SSD noted that main-sequence mass loss may well be associated with this intersection of the instability strip with the main sequence. SSD noted that lithium limits such main-sequence mass loss and that some mass loss (total loss of $\lesssim 6\%$) could explain the Pop I dip. In this letter we show that the model, when extended to Pop II stars, fits the observations quite well. It can even explain why stars with very similar surface temperatures can show different levels of lithium depletion. Such observations may be difficult to understand in the diffusion model. As Willson, Bowen & Struck-Marcell (1987) also noted, main sequence mass can affect globular cluster ages. This point will be briefly discussed here.

THE CALCULATION

Pop II compostion, low mass main sequence stars with surface temperatures from 5500K to 7000K were evolved with assumptions regarding mass loss, compositions, etc. The main points of relevance to the lithium dip are discussed below. In particular, Figure 1 shows the surface lithium abundance as a function of age and surface temperature, T_{eff} for Population II composition stars with metalicity Z = 0.0004 and X = 0.75. We used the primordial lithium composition given by the Spite plateau value of $\frac{Li}{H} = 1.5 \times 10^{-10}$. The effect of instability strip mass loss was modeled by simply setting a mass loss rate of $10^{-11} M_{\odot}$/yr within an instability strip of 6600 < T < 6900K with zero elsewhere. This temperature strip was chosen from RR-Lyrae stars. However, we realize that the Pop II main sequence strip could be slightly displaced. Thus, in principle, this range could be adjusted (or actually calculated), but we did not do so in this set of calculations. The curves of Figure 1 were generated by evolving stars at ΔM increments of $0.02 M_{\odot}$ masses from 0.80 to 1.00 $M_{\odot}$.

The low temperature decrease shown in Figure 1 in lithium is the standard effect of the deeper convective zone in lower mass stars and not related to the mass loss discussed here. The central plateau is the well-known Spite plateau. Notice that the width of the depleted region grows with age. The right end points of the 9 Gyr and 11 Gyr isochrones are 0.94 $M_{\odot}$ and 0.86 $M_{\odot}$. The other isochrones end at the 1 $M_{\odot}$ model.

The Pop II stars calculated here have convective zones ranging in mass from $2 \times 10^{-3} M_{\odot}$ for the 0.80 $M_{\odot}$ star to $10^{-6} M_{\odot}$ for the 1.00 $M_{\odot}$ star. The convective zone for the $0.84 M_{\odot}$

star, where our mass loss sets in, is $5 \times 10^{-4} M_\odot$. Thus, small mass loss rates can deplete the initial convective zone and regenerate one with material that was previously in the higher temperature radiative domain where lithium was depleted. The thin Pop II convective zones can be compared with the $0.02 M_\odot$ Pop I convective zone of our Sun. It should also be remembered that as Z increases, it will take a higher mass star to have a surface temperature high enough to hit the instability strip. Thus, in the SSD Pop I Li-dip paper, the dip stars are above $1 M_\odot$. As Z decreases, lower mass, longer lived stars are able to hit the instability strip.

The point labeled "PT" in Figure 1 is a 1.00 $M_\odot$ post-main-sequence-turnoff point for the 9 Gyr lithium isochrone. As stars evolve, they increase slightly in T_{eff} until they leave the main sequence when they begin to cool rapidly. The star PT of Figure 1 was caught during this rapid cooling phase. For this temperature range and age, the probability of observing a post-main-sequence-turnoff star cooling down is about 8%. In fact, Figure 2 shows the surface temperature versus fractional pre-red giant lifetime for Pop II stars with $0.80 \lesssim M \lesssim 1.0 M_\odot$ and a mass loss rate of $\dot{M} = 10^{-11} M_\odot$/yr for an instability strip ranging from 6600 < T < 6900K. Notice that about 12 to 15% of the pre-red giant lifetime occurs after the peak surface temperature. This effect requires an occasional Li depleted star at a temperature below the main "dip temperature," though the number of such objects is sufficiently small that the Spite-plateau appears intact. The post-main-sequence-turnoff (PT) stars will be slightly brighter (about 1 to 1.5 magnitudes) and have slightly lower surface gravity (log g down by ~ 0.5) than pre-turnoff, zero-age main-sequence stars of the same temperature. This may provide a test for the model. In comparing the calculations with actual data from Hobbs, Welty & Thorburn (1991), one might wish to identify the PT star with G186-26 and a plateau star at the same temperature with BD+3-740.

Another effect that can produce some scatter at the edge of the dip is the correlation of the width of the lithium depleted region with decreasing metalicity. In particular, for a fixed age, the region of depleted lithium increases as the metalicity decreases. For example, in the SSD Population I study, the width of the dip is noticibly narrower in T_{eff} than it is in these extreme Pop II studies.

Figure 3 shows the relative depletion of ^{9}Be in the dip region for different age Pop II stars, assuming a constant initial ^{9}Be abundance. Note that the ^{9}Be depletion at a given age is significantly less than the ^{7}Li depletion. Also, the width of the ^{9}Be dip is narrower than the ^{7}Li dip with other parameters held constant. The prediction of a reduced but non-zero beryllium depletion in dip stars makes a useful and important test of this model. However, it should be remembered that beryllium is not produced in the standard homogeneous Big Bang model (c.f. Schramm & Wagoner 1977). Hence, Be abundances are expected to correlate with metalicity and not show a Spite-like plateau. In fact, all current Pop II beryllium data does in fact correlate with metalicity (Ryan et al. 1990; Gilmore, Edvardson & Nissen 1991) as is expected in cosmic ray spallation models for the origin of Be and B (Walker et al. 1992). Thus, the establishment of ^{9}Be depletion also requires measurement of ^{9}Be for lower T_{eff} stars of the same metalicity to establish a baseline.

Willson, Bowen and Struck-Marcell (1987) have pointed out how main-sequence mass loss of the type discussed here can alter globular cluster age determinations. We note in our calculations that the maximum effect, consistent with Pop II Li depletion, is a decrease in the age by $\sim$1 Gyr at turnoff relative to stars with no mass loss. (Low mass stars whose tracks do not intercept the instability strip will obviously have no such apparent age shift.) One interesting effect of instability strip mass loss is the generation of a small "hump" in a globular cluster's luminosity function similar to that observed by Stetson (1991). We will explore these potential globular cluster effects in more detail in a subsequent paper where the sensititivity to the exact position of the Pop II main sequence instability strip will be investigated. Such an investigation is beyond the scope of this letter.

CONCLUSION

We have shown that the observed Pop II lithium dip can be explained using the same main-sequence mass loss model as was used to provide an explanation for the Pop I lithium dip. This mechanism can also decrease globular cluster ages. Further data on lithium (and possibly beryllium) depletions for different surface temperatures and metalicities will help elucidate the mechanism. We explicitly note that this model (as well as the alternate diffusion model for the dip) in no way affects the previously noted cosmological implications of the lithium plateau itself.

ACKNOWLEDGEMENTS

We would like to acknowledge our earlier collaborator, Gary Steigman, for his comments and his continued interest in this work. This work was supported in part under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract No. #W-7405-ENG-48; at the University of Chicago by NSF grants # AST-90-22629 and # AST-91-19121 and by NASA grant # NAGW 1321; and at NASA/Fermilab by the DoE and by NASA grant # NAGW 2381. David N. Schramm would also like to acknowledge the Miller Research Foundation and the hospitality of the University of California at Berkeley where this work was completed.

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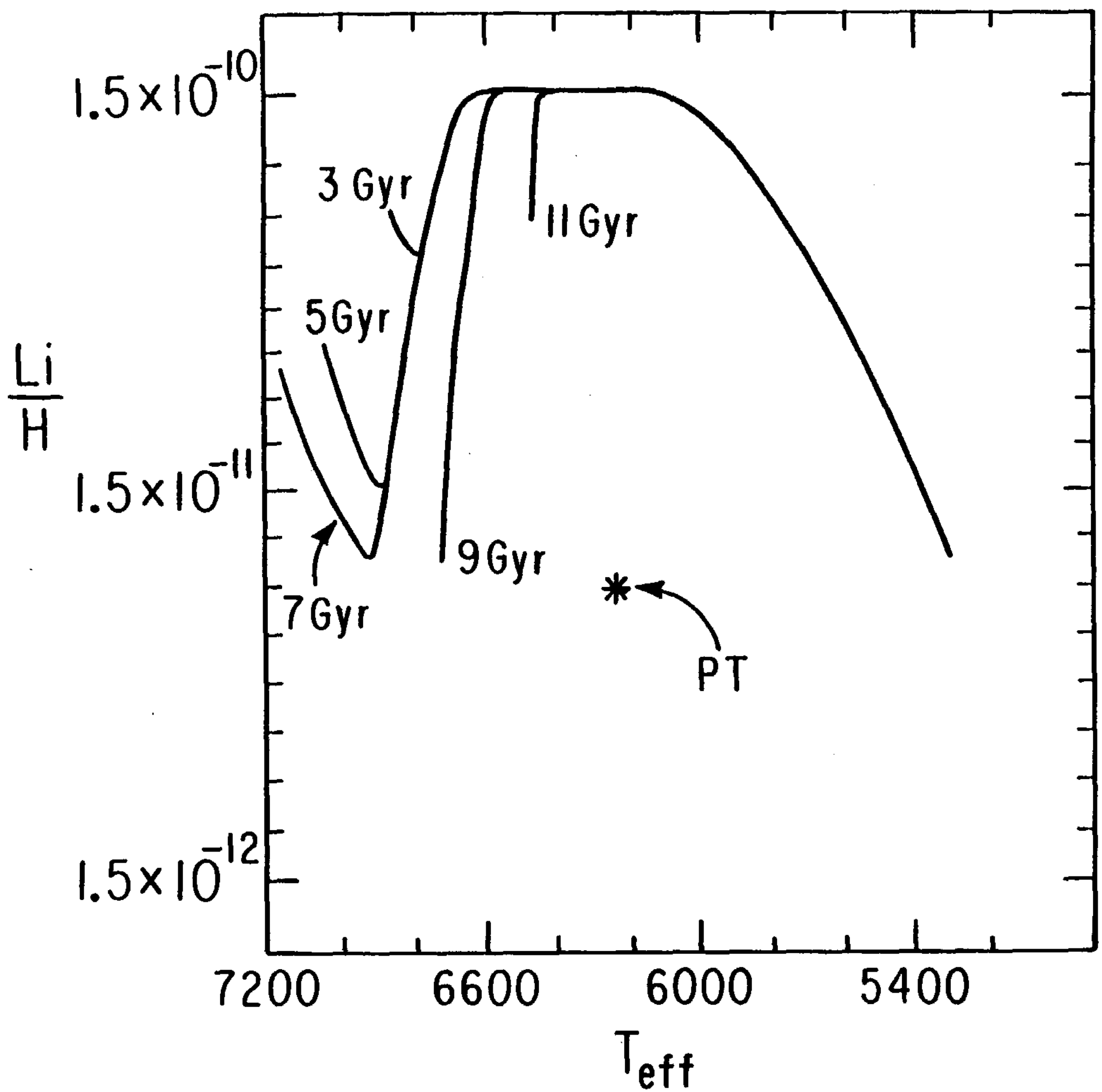
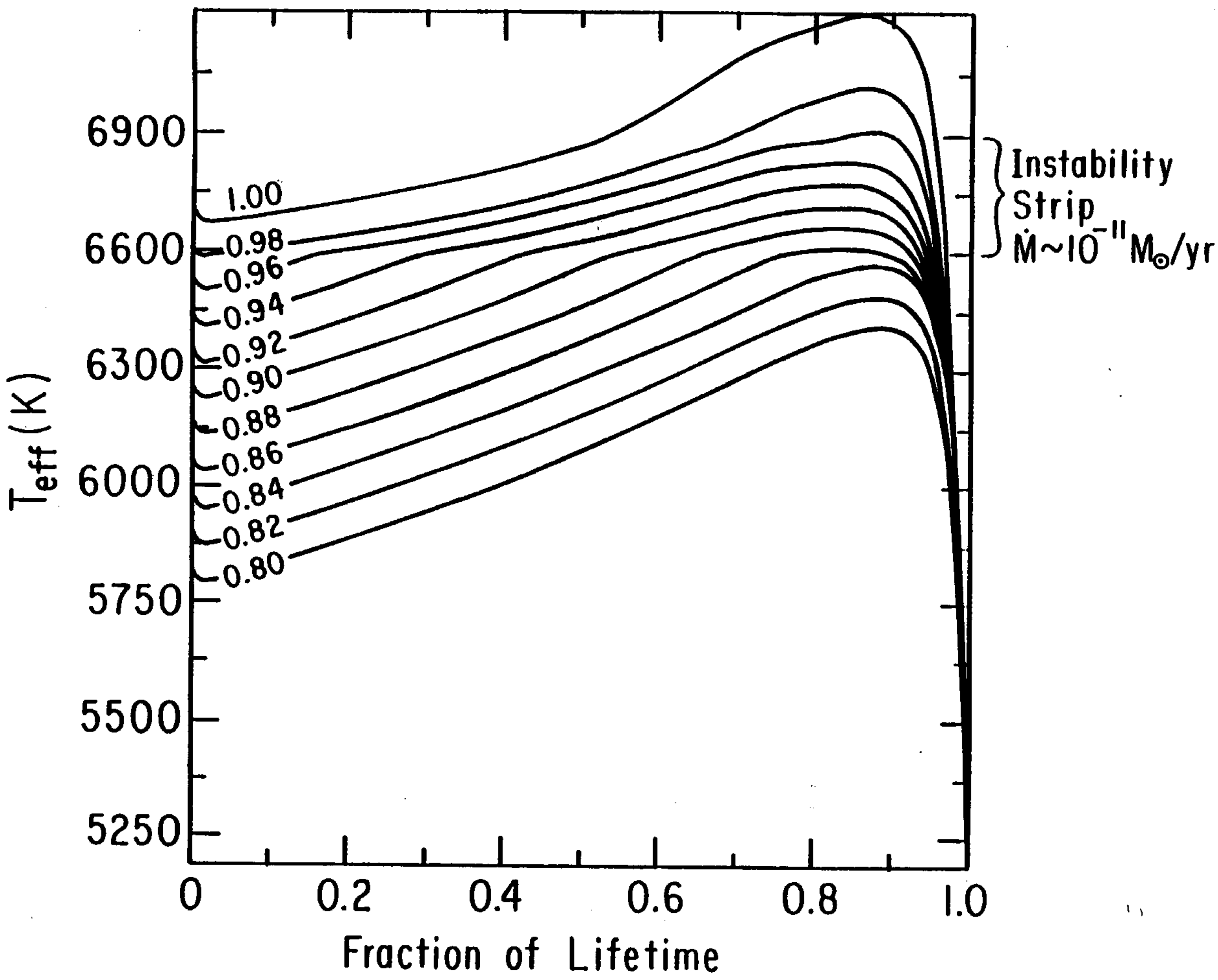
FIGURE CAPTIONS

Figure 1. The surface lithium abundance as a function of age and surface temperature, T_{eff} for Population II composition stars with metalicity Z = 0.0004 and primordial lithium composition given by the Spite plateau value of $\frac{Li}{H} = 1.5 \times 10^{-10}$ and a mass loss rate of $10^{-11} M_{\odot}$/yr within an instability strip of 6600 < T < 6900K. The point labeled "PT" is a star that is post-main-sequence-turnoff from the 9 Gyr isochrone.

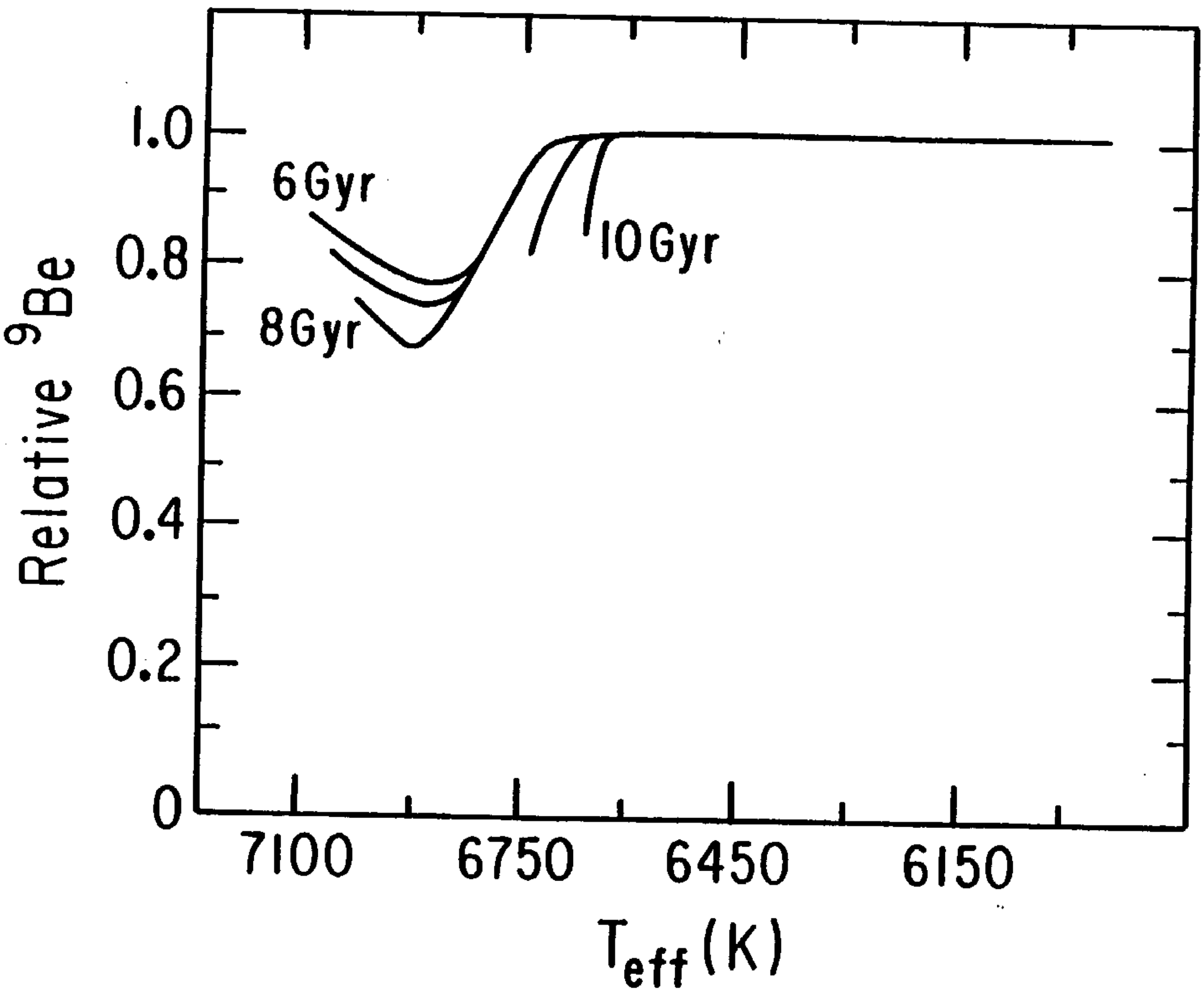
Figure 2. Surface temperatures versus fractional pre-red giant lifetime for Pop II stars with $0.80 \lesssim M \lesssim 1.0 M_{\odot}$ and mass loss rate of $\dot{M} = 10^{11} M_{\odot}$/yr for $6600 \lesssim T \lesssim 6900$K.

Figure 3. The relative depletion of ^{9}Be in the dip region for different age Pop II stars, assuming a constant initial ^{9}Be abundance.


Li/H
1.5×10⁻¹⁰
1.5×10⁻¹¹
1.5×10⁻¹²
3 Gyr
5Gyr
7Gyr
9Gyr
11Gyr
PT
7200
6600
6000
5400
Teff



T_{eff} (K)
6900
6600
6300
6000
5750
5500
5250
0
0.2
0.4
0.6
0.8
1.0
Fraction of Lifetime
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
Instability Strip
$\dot{M} \sim 10^{-11} M_{\odot}/yr$


Relative ^{9}Be
1.0
0.8
0.6
0.4
0.2
0
6Gyr
8Gyr
10Gyr
7100
6750
6450
6150
T_{eff} (K)